HAZARD DIVISION 1.2 TESTS--INSTRUMENTATION RESULTS AND INTERPRETATION

by

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ABSTRACT

To date, nearly all efforts in the field of accidental explosion consequence determination have been aimed at the quantification of the effects of a Hazard Division (HD) 1.1 event. Little attention has been paid to the consequences of the ignition of stacks of Hazard Division 1.2 ammunition. In 1989, NATO AC/258 (Group of Experts on the Safety Aspects of Transportation and Storage of Military Ammunition and Explosives) agreed that a program of trials should be carried out to investigate the consequences of an HD 1.2 event. The goal of these trials would be twofold: to gain basic knowledge about HD 1.2 phenomena and to revise the current NATO quantity-distance relationships for HD 1.2 events.

As a result of the NATO interest, a joint UK/US experimental program was started in 1990. To date, seven tests have been conducted: three single-pallet tests (30 projectiles/test), two eight-pallet tests (240 projectiles/test), one twenty-seven pallet test (864 projectiles), and one three-pallet test (96 projectiles loaded with Composition B). This report describes the test program, the instrumentation which was utilized, and summarizes some of the results which have been obtained.

INTRODUCTION

To date, nearly all international effort in the field of accidental explosion consequence determination has been aimed at the quantification of the effects of a Hazard Division (HD) 1.1, mass detonation, event, in an explosives storage facility.

Little attention has been paid to quantifying the consequences of the accidental initiation of HD 1.2 ammunition. This class of ammunition is not expected to explode en masse. Individual rounds or small groups of rounds will explode when sufficiently stimulated (by, for example, fire) without causing others around them to explode. Such explosions will continue spasmodically over a period as further rounds receive sufficient stimulus.

A more detailed discussion of the entire program is presented in the paper Trials to Determine the Consequences of the Accidental Ignition of Stacks of HD 1.2 Ammunition M. J. A. Gould,

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TEST PROGRAM

The test program consists of a series of bonfire tests on various sized stacks of HD 1.2 items stored in the open. Seven tests have been completed thus far in the testing program. The test details are presented in Table 1. All of these tests were conducted at the Naval Air Warfare Center, Weapons Division, China Lake, California.

The ammunition which has been tested to date is the M1 105mm cartridge. This is a semi-fixed, high explosive artillery round. The projectile body is fabricated from forged steel and weighs approximately 25.8 pounds. Tests 1 through 6 used TNT as the explosive fill, while Test 7 used Composition B.

The cartridges are packaged in wooden boxes for transport and storage. Each box contains two cartridges that are oriented such that the projectile of one cartridge is adjacent to the propelling charge of the other cartridge (i.e., nose-to-tail arrangement. A complete pallet consists of 15 or 16 boxes, depending on the stacking arrangement. The boxes are secured on the pallet using steel banding.

INSTRUMENTATION

<u>AIRBLAST</u>. This section describes the transducers and instrumentation that were used during the HD 1.2 Tests. The first five tests, tests #1 through #3 (single pallet of projectiles) and tests #4 and #5 (eight pallets of projectiles), used eight pressure gauges located at the 0 and 90 degree radii as shown in Figure 1. Four gauges were located on each radii at nominal ranges of 50, 70, 100 and 200 feet from the center of the pallet or stack of pallets. Each gauge was mounted two feet above the ground. Gauge positions were labeled P1 through P8, as shown in Figure 1.

Test number 6, using 27 pallets of projectiles and test # 7 using 3 pallets of projectiles, utilized 12 pressure gauges which were located along the 0, 90, and 225 degree radials as shown in Figure 1. Four gauges were located on along each line at nominal ranges of 50, 70, 100 and 200 feet from ground zero. Gauge positions were labeled P1 through P12 for these tests. Also during tests number 6 and 7, an optical zero time transducer was used so that the projectiles initiation time could be determined. This will be discussed in more detail below.

The pressure gauges that were used during the tests are the Atlantic Research Corporation Blast Pressure Gage Model LC-33. The sensing element is piezoelectric and mounted in a pencil type housing as shown in Figure 2. The output of the gauge is connected to a source follower amplifier (PCB Model 402A02), located near the gauge. The PCB source follower amplifier is powered and conditioned through the PCB Power Unit Model 494A06. The gauge-amplifier was located approximately 600 feet from the power unit and recording system. The overall frequency response of the gauge and conditioning system is 0.5 to 100,000 Hz.

OPTICAL ZERO TIME SENSOR. During tests 6 and 7, a zero-time optical sensor was used to determine the initial reaction time of each event. Test 6 used a fiber optic cable as input to a photoconductor in order to keep the electronics away from the test event. The fiber optic zero time sensor consisted of four parts: (1) fiber optic input block, (2) interconnecting fiber optic cable, (3) photoconductor, and (4) amplifier and filter. Figure 3 shows the fiber optic input block and a schematic of the photoconductor-amplifier circuit. The fiber optic input block was configured in this way in order to expand the sensors field of view. The optical sensor used was the Clairex CL-704L photoconductor. This was used mainly because of its availability and because of its low resistance characteristics. The Texas Instruments Tl-054 operational amplifier was used at a gain of approximately 1000. The circuit also has a high pass filter set to 2,000 Hz, removing the slower intensity changes of the cook-off fire from the dynamic flare-up produced by each event. For test number 7, the optical zero time unit was redesigned. It was determined that by placing the photoconductors closer to the event that a wider field of view would be established. Thus, the need for the fiber optic cable was eliminated. The extra input to to the the circuit was added at the 180 degree radial to reduce the possibility of an event indication being shielded by the stacks of projectiles. All other parts of the system were kept the same as the previous design.

TEMPERATURE. On Test 6, an attempt was made to measure the temperature on both the outside and inside of several of the boxes. High temperature Type K thermocouples were used. The locations of these sensors is shown in Figure 4a. On Test 7 temperature measurements were also made. The locations of these sensors are shown in Figure 4b.

The thermocouples were connected to an Analog Devices AD595 thermocouple amplifier with a built-in cold junction compensator. The circuit was packaged and buried approximately 30 feet from the center of the pallet stack. The output of the amplifiers were connected to a HW101 FM tape recorder located approximately 600 feet away. Time code was also recorded on the tape so that the temperature data could be coordinated with the blast data. The tape recorder was operated at a speed of 15 inches per second (ips) which gave a recording time of approximately two hours and a frequency response of DC to 10 KHz. The recorder was operated manually and turned-on before leaving the test site.

REMOTE INSTRUMENTATION FLOAT SYSTEM. The pressure measurements were recorded remotely using a radio controlled instrumentation system. The instrumentation system was designed originally for recording shockwave measurements near large underwater explosions; it was designed to be placed on a remote floating platform. Thus it is named the Remote Instrumentation Float System (RIF). Appropriate modifications were made in order to meet the requirements of the HD 1.2 tests. A remote controlled recording system was required because of the lack of appropriate shelter for instrumentation and personnel at the test site. Tests 1 through 3 used one RIF system and tests 4 through 7 used two systems. Two systems were required because a single system had a recording duration that was potentially too short to record the complete test. Thus, two RIF system were used in series with a short time of recording overlap.

The RIF System is a rugged, shock mounted, air-conditioned, self contained recording system.

The remote unit is controlled and monitored through Dual Tone Multi-Frequency encoded radio transmissions from up to three miles. The instrumentation can be powered with battery/inverter systems or a portable generator. The overall RIF system is shown in block diagram form in Figure 5. The RIF system is controlled by a master remote control station that sends commands and receives the remote RIFs' status reports through Dual Tone Multi-Frequency encoded radio transmissions. Five watt Motorola PT500 FM transceivers are used for these transmissions. During this test series, the recording system was controlled from a distance of approximately 4000 feet.

The FM tape recorder used in the RIF system is the Honeywell Model 101 (HW101). During the tests, the recorder was set for Wideband I recording and the data was recorded at 30 ips to give a frequency response of DC to 20 KHz. The 9600 foot tapes which were used during the tests gave approximately 58 minutes of recording time. The HW101 is operated in the remote mode which enables operation of front panel controls through the remote connector. Through this connector, the HW101's status is also monitored.

The RIF system is powered by two sets of battery/inverter systems for DC and AC power. One set has two 80 ampere-hour batteries and an inverter that supplies power to the data collection electronics; power is switched on by the remote control electronics and the batteries operate for 60 minutes. The other set has a 40 ampere-hour battery and inverter that supplies power to the remote control electronics for up to ten hours of operation. The RIF system can also be powered by a portable gasoline powered generator. Due to the long recording times required for these tests, generators were mostly used.

<u>DATA REDUCTION</u>. Data reduction of the information recorded during testing was done at the White Oak facility of the Naval Surface Warfare Center. Tests 1 through 5 were analyzed using Hewlett Packard HP1000A minicomputer systems that digitize and process data previously recorded on analog tape recorders. These systems provide laserjet plots along with the capability of providing ASCII data files that can be used on personal computers. A block diagram of the system is shown in Figure 6. The computer system was recently upgraded and expanded to include four Hewlett Packard HP9000/700 series work stations and Kinetic Systems transient recorders/digitizers. This system was used for digitizing and processing the data for tests 6 and 7. Also incorporated in the data reduction system was a time code reader with a time code latch circuit. The time code latch circuit freezes the time code reader display when a signal is input into the circuit. Thus, when the trigger latch circuit was connected to a recorder data channel output, the shockwave signal would latch time code and show the time the event occurred.

RESULTS

This section summarizes the instrumentation results which have been obtained to date during this testing effort. Typical pressure-time waveforms are presented. All temperature data will also be summarized

<u>Test Number 1</u> This test was of a single pallet of projectiles (total of 30 projectiles) and was conducted in May 1991. Due to shipping problems, the instrumentation did not arrive at the test

site in time. Therefore, there are no airblast data for this test. Thirteen events were recorded and seventeen projectile bodies were recovered--accounting for all 30 projectiles.

Test Number 2 The second test was also a single pallet of projectiles; it was conducted in June 1991. Nine events or major reactions were recorded on this test.

Test Number 3 The third test was a single pallet of projectiles and was conducted on July 29, 1991. Eleven events or major reactions occurred on this test. However, the last two events happened after the shut down of the tape recorder (more than 1 hour after the start of the fire). Eleven events were recorded; nineteen projectile bodies were recovered--accounting for all 30 projectiles.

Test Number 4 The fourth test consisted of eight pallets of projectiles (total of 240 projectiles) and was conducted on August 29, 1991. Following the test, 174 projectile bodies were recovered intact--indicating that 66 projectiles had reacted. Based on the on-site observations and the pressure instrumentation, sixty-eight events or major reactions occurred. The pressure instrumentation indicated more reactions than there were missing projectiles--this discrepancy can be attributed to propellant-type reactions which were mistaken for projectile reactions. If a true zero time had been available, allowing the location of each event to be determined, then these propellant reactions could have been identified.

Test Number 5 The fifth test consisted of eight pallets of projectiles and was conducted on April 29, 1992. Following the test, 174 projectile bodies were recovered intact--indicating that 66 projectiles had reacted. Based on the on-site observations and the pressure instrumentation, sixty-nine events or major reactions occurred. The pressure instrumentation indicated more reactions than there were missing projectiles--this discrepancy can be attributed to propellant-type reactions which were mistaken for projectile reactions. If a true zero time had been available, allowing the location of each event to be determined, then these propellant reactions could have been identified.

Test Number 6 The sixth test consisted of 27 pallets with each pallet containing 32 projectiles for a total of 864 projectiles. This test was conducted on October 28, 1992. Following the test, 546 projectile bodies were recovered intact--indicating that 318 projectiles had reacted. Based on the on-site observations and the pressure instrumentation, 324 events or major reactions occurred. A zero-time sensor was available for this event, therefore shock time of arrival and event locations could also be determined.

There are several events for which no event zero time was measured. This could be due any of several causes. Two of the most likely, however, include: (1) the fiber optic zero time sensor becoming saturated from an event which occurred momentarily before the next reaction (2) some reactions may have been shielded from the zero time sensor if the reaction occurred on the opposite side of the stack from which the sensor was located.

The difference between the number of reactions determined from the instrumentation and the number of unrecovered projectiles can be attributed to propellant reactions. These reactions will be separated out and discussed in the following section.

Figure 7 presents a sample of the pressure-time waveforms which were recorded on this test. Also presented is the shape of the zero time pulse which was recorded for this event.

According to the pressure and optical instrumentation, the first event occurred approximately 26 minutes after the start of the fire. The zero time for the thermocouple analysis was adjusted to the time for Event 1. Any thermocouple readings taken beyond a time of approximately 25 minutes would, therefore, be suspect. Table 2 presents the maximum temperatures which occurred in the first 24 minutes of the fire.

Test Number 7 The seventh test consisted of three pallets with each pallet containing 32 projectiles for a total of 96. The test was conducted on April 29, 1994. Each projectile contained Composition B explosive and was assembled with a supplementary charge. The projectiles were received with mechanical time fuses installed. These fuses were removed to comply with range safety requirements. Following the test, 82 projectile bodies were recovered intact--indicating that 14 projectiles had reacted. Based on the pressure measurements and on-site observations eight major reactions occurred. These data are still under analysis; therefore, they will not be further discussed.

ANALYSIS/INTERPRETATION

Only the data from Test 6 will be discussed further. This is for two reasons. Firstly, because of the large number of events involved, all of the other tests can be interpreted as sub-sets of the Test 6 data. Secondly, Test 6 provided true shock time of arrival for each event at each transducer. This allows an estimate of the event location to be made. Once the event location is determined, a yield that is based on its pressure-distance decay characteristics can be determined.

This section describes the methodology which was used to estimate each event location. It then presents in both tabular and graphical form the locations determined for each event. The second half of the section deals with the determination of yield for each event. It describes the methodology which was applied and then discusses the results which were obtained--i.e., those events which appeared to be high order detonations (100% yield) and those events which were merely propellant reactions (approximately 0.1% yield or less).

DETERMINATION OF EVENT LOCATIONS. An iterative procedure was set up to determine the location of each event. Because the airblast overpressures were quite low, usually below 1 or 2 psi, it was assumed that the signal propagated at sonic velocity. It was further assumed that because of the fire, there was a sound velocity gradient across the ground zero area--with the sound velocity proportional to the ambient temperature.

The procedure works as follows and would be repeated for each event. An arbitrary event location is chosen (usually, the center of the ground zero area--coordinates (0,0)). Arrival times

are calculated to each gauge position: radial distance between chosen event location and known gauge position divided by the sound velocity. The calculated arrival time is subtracted from the measured arrival time and the resulting difference is squared. This squared difference is summed for all of the gauge positions (P1 through P12). The event location which is reported is that location that minimizes this squared difference.. As a sensitivity check on the procedure, a constant propagation velocity (no fire-induced gradient) was assumed and several of the cases were re-run. The differences in the final locations were not significant. Because of the assumptions which were involved, it is the authors judgement that the locations presented are only accurate to about ± 5 feet.
These locations are presented in Figures 8, 9, and 10. These are scatter plots showing the locations of the events around the ground zero area. The immediate ground zero area was covered by a 20 x 20 concrete pad. This pad is also shown in the Figures, which are simply different views of the same information.

DETERMINATION OF EVENT YIELDS. Two questions will be addressed in this section. The first is Of those events analyzed for Test 6, which ones were produced by propellant reactions? The second is Which events were true high order detonations?

Based on the description of the charge which was presented earlier, airblast predictions were made using Porzels Unified Theory of Explosions[11]. Three predictions were made--a 100% yield (high order detonation), a 5% yield, and a 0.5% yield; these are shown in Figure 11. The 100% yield represents the predicted curve for the detonation of 4.5 pounds of TNT inside a 105 mm projectile body weighing approximately 24 pounds; the 0.5% yield, represents the detonation of 0.0225 pounds (10 grams) inside the same projectile body. These prediction curves were then used to calibrate a yield determination program--DSC[11]. The program DSC was written around concepts and techniques which were developed for the analysis of nuclear blast yields. The program evaluates a pressure-distance curve and produces an absolute yield in megacalories. The data which were presented in Figure 11 were run through the DSC program to provide a relationship between absolute yield in megacalories and a relative yield in percent. These relative yields in percent are the yields which are required for this analysis.

The pressure-distance curves generated for each event were then analyzed using the computer program DSC. When an event location was not known, a location was assumed and an approximate pressure-distance curve was generated. The absolute yields which were determined were converted to relative yields. These results are presented in Figure 12.

Based on the numbers of recovered projectiles, it is assumed that 318 projectiles reacted; 324 events were recorded and tabulated. Examining Figure 12, the six events with the lowest yields were selected as propellant events. All of the selected events had yields of less than 0.10%.

One event was produced by a high order detonation with a yield of 100%. This was an event for which there was no zero time. Thus an estimated position was used to make the yield determination.

When the six propellant events are excluded, the average yield which was observed was 10%.

If Figure 12 is examined closely, another trend can be discerned. As the event number increases, corresponding to increasing time after the first event or the start of the fire, the yield seems to be increasing. This may be analogous to what is observed in cook-off testing, where slow cook-off tests produce more violent results than do fast cook-off tests.

SUMMARY

The instrumentation described is providing valuable insight into the HD 1.2 phenomena. Based on all of the data which have been obtained to date, the HD 1.2 event appears to be a popcorn-type reaction, with events occurring sequentially rather than simultaneously.

A more detailed description of the information contained in this paper is presented in NSWCDD/TR-93/218.[12]

REFERENCES

1. Henderson, J., Joint Australian/UK Stack Fragmentation Trials Phase 4 Preliminary Report, Minutes of the 24th DoD Explosives Safety Seminar, August 1990.

2. Henderson, J. ,Rees, N. M. J. Joint Australian/UK Stack Fragmentation Trials Preliminary Phase 3 Report, Minutes of the 23rd DoD Explosives Safety Seminar, August 1988.

3. Henderson, J. et. al., Joint Australian/UK Stack Fragmentation Trials Phase 2 Report, Minutes of the 22nd DoD Explosives Safety Seminar, August 1986.

4. Bowman, F., et. al., Joint Australian/UK Stack Fragmentation Trials Phase 1 Report, Minutes of the 21st DoD Explosives Safety Seminar, August 1984.

5. Roger, M., Assessment of Hazardous Areas When Storing HD 1.1 Ammunition in French IGLOO TYPE Magazines, Minutes of the 25th DoD Explosives Safety Seminar, August 1992.

6. Swisdak, M. M., Hazards Produced By Explosions Inside Earth-Covered Igloos, Minutes of the 25th DoD Explosives Safety Seminar, August 1992.

7. Joachim, C., Shallow Underground Tunnel/Chamber Explosion Test, Minutes of the 24th DoD Explosives Safety Seminar, August 1990.

8. Joachim, C., Accidental Detonations In Underground Munitions Storage Magazines: Predictions of Cover Rupture Pressure, Minutes of the 24th DoD Explosives Safety Seminar, August 1990.

9. Joachim, C., Ejecta Hazard Ranges From Underground Munitions Storage Magazines, Minutes of the 24th DoD Explosives Safety Seminar, August 1990.

10. United Nations Recommendations on the Transport of Dangerous Goods, Tests and Criteria, Second Edition, ST/SG/AC.10/11/Rev 1.

11. Porzel, F. B., Technology Base of the Navy Explosives Safety Improvement Program, Minutes of the 19th DoD Explosives Safety Seminar , Sep 1980.

12. Swisdak, M. M., Jr. and Rye, Kent W., Hazard Division 1.2 Tests--Instrumentation Results and Interpretation, NSWCDD/TR-93/218, 9 March 1994.

TABLE 1 TESTING PROGRAM

TEST NUMBER	NUMBER OF PALLETS	BOXES PER PALLET	NUMBER OF ROUNDS	TEST DATE	INSTRUMENTATION
1	1	15	30	7-May-91	photography
2	1	15	30	24-Jun-91	photography, airblast
3	1	15	30	29-Jul-91	photography, airblast
4	8	15	240	29-Oct-91	photography, airblast
5	8	15	240	29-Apr-92	photography, airblast
6	27	16	864	28-Oct-92	photography, airblast, temperature
7	3	16	96	3-May-94	photography, airblast, temperature

TABLE 2 TEST 6 TEMPERATURE DATA

POSITION IN STACK	BOX NUMBER	DESCRIPTION	MAXIMUM TEMPERATURE (°C)
2BZ	9	in projectile	500
2BX	3	in projectile	100
2BZ	9	top of box	135
2BX	3	top of box	980
1AY	3	top of box	700
2BZ	13	in projectile	290
2BZ	13	face of box next to adjacent pallet	1190
2BY	15	outward face of box	700
3BY	13	outward face of box	1040

TABLE 3 TEST 7 TEMPERATURE DATA

POSITION IN STACK	BOX NUMBER	DESCRIPTION	MAXIMUM TEMPERATURE (°C)
Bottom Right	4	Flame Beneath Pallet	1194
Bottom Right	4	Fuse Well	125
Bottom Right	4	Projectile Case	90
Top Box	4	Flame Beneath Pallet	1167
Top Box	4	Fuse Well	50
Top Box	4	Projectile Case	90
Bottom Left	4	Fuse Well	779
Bottom Left	4	Projectile Case	200
Bottom Left	4	Flame Beneath Pallet	Bad

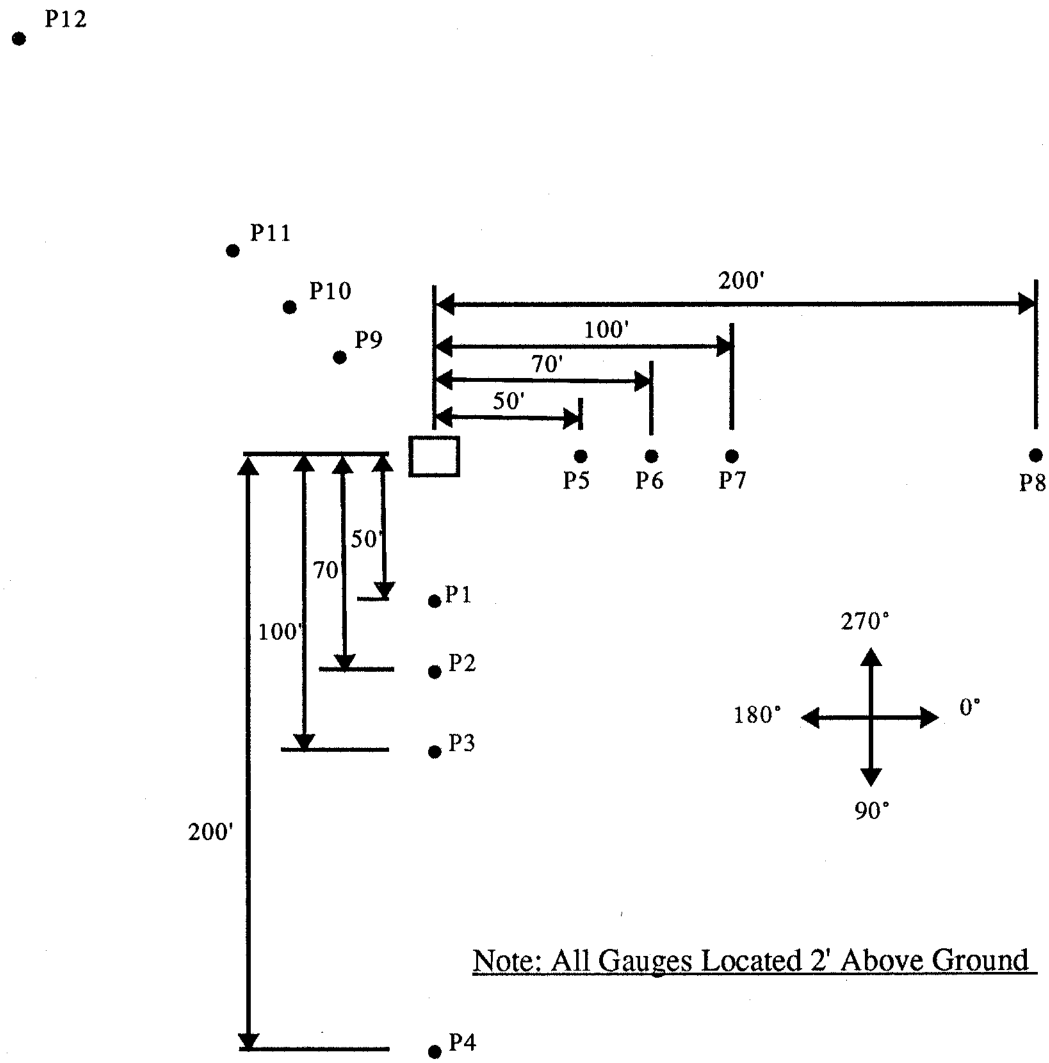


FIGURE 1 PRESSURE GAUGE LOCATIONS

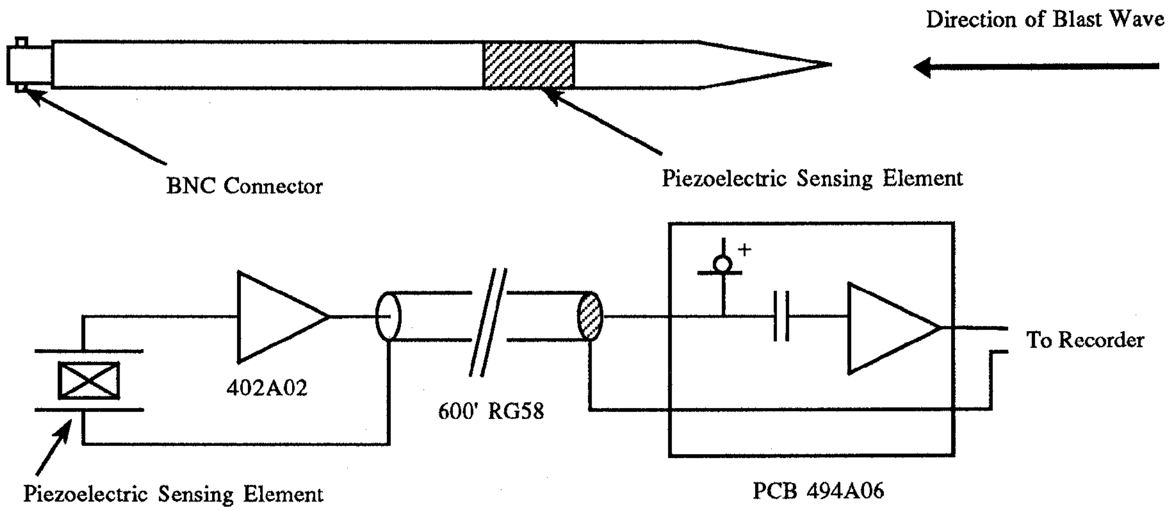


FIGURE 2. MODEL LC-33 PRESSURE GAUGE AND CIRCUIT SCHEMATIC

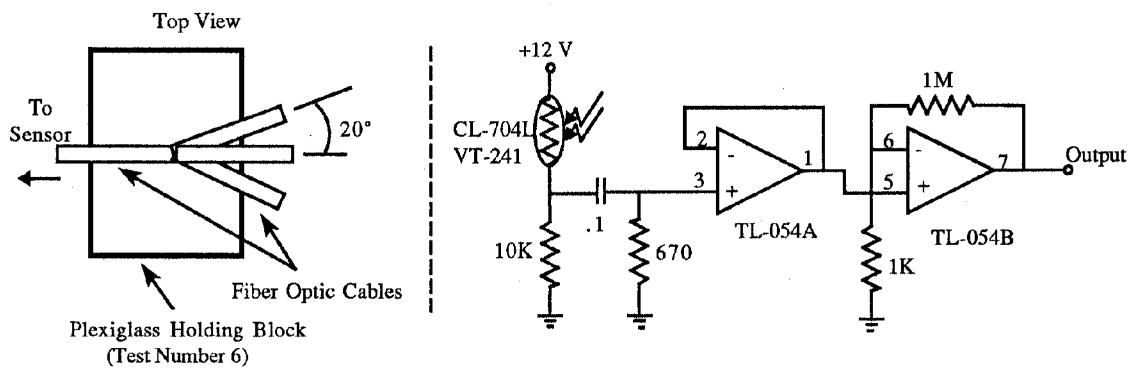
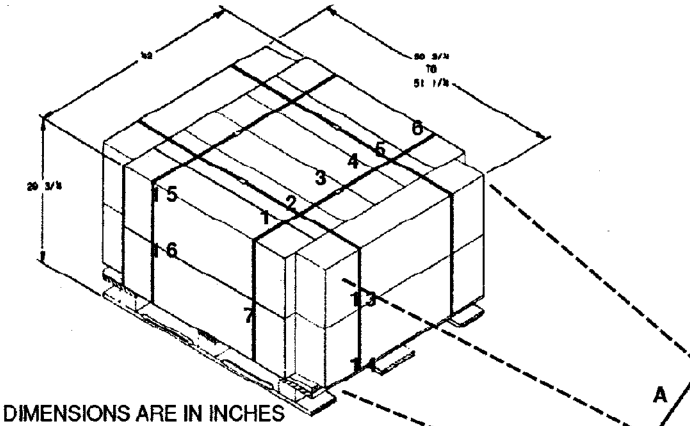
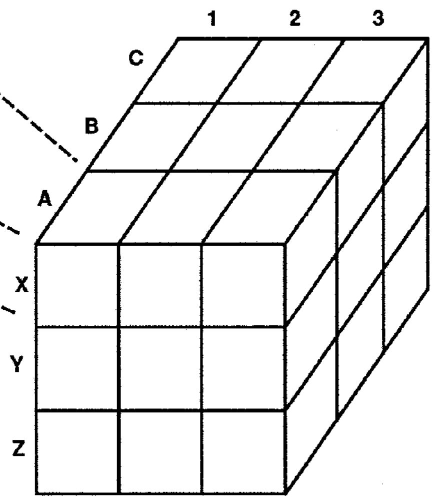


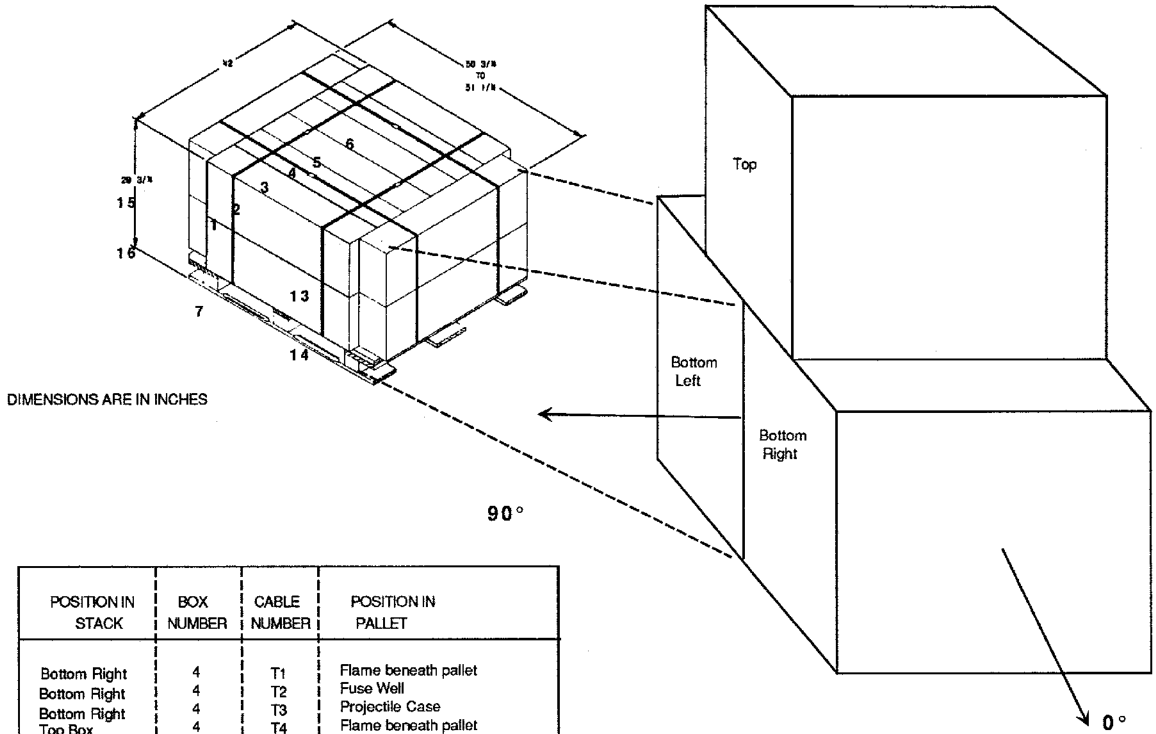
FIGURE 3 FIBER OPTIC INPUT BLOCK AND CIRCUIT SCHEMATIC





Position in Stack	Box	Cable	Position in Pallet
2BZ	9	21	in projectile
2BX	3	22	in projectile
2BZ	9	30	top of box
2BX	3	24	top of box
1AY	3	25	top of box
2BZ	13	26	in projectile
2BZ	13	27	face of box next to adjacent pallet
2BY	15	28	outward face of box
3BY	13	29	outward face of box

FIGURE 4a THERMOCOUPLE LOCATIONS TEST 6



POSITION IN STACK	BOX NUMBER	CABLE NUMBER	POSITION IN PALLET
Bottom Right	4	T1	Flame beneath pallet
Bottom Right	4	T2	Fuse Well
Bottom Right	4	T3	Projectile Case
Top Box	4	T4	Flame beneath pallet
Top Box	4	T5	Fuse Well
Top Box	4	T6	Projectile Case
Bottom Left	4	T7	Fuse Well
Bottom Left	4	T8	Projectile Case
Bottom Left	4	T9	Flame beneath pallet

FIGURE 4b THERMOCOUPLE LOCATION TEST 7S

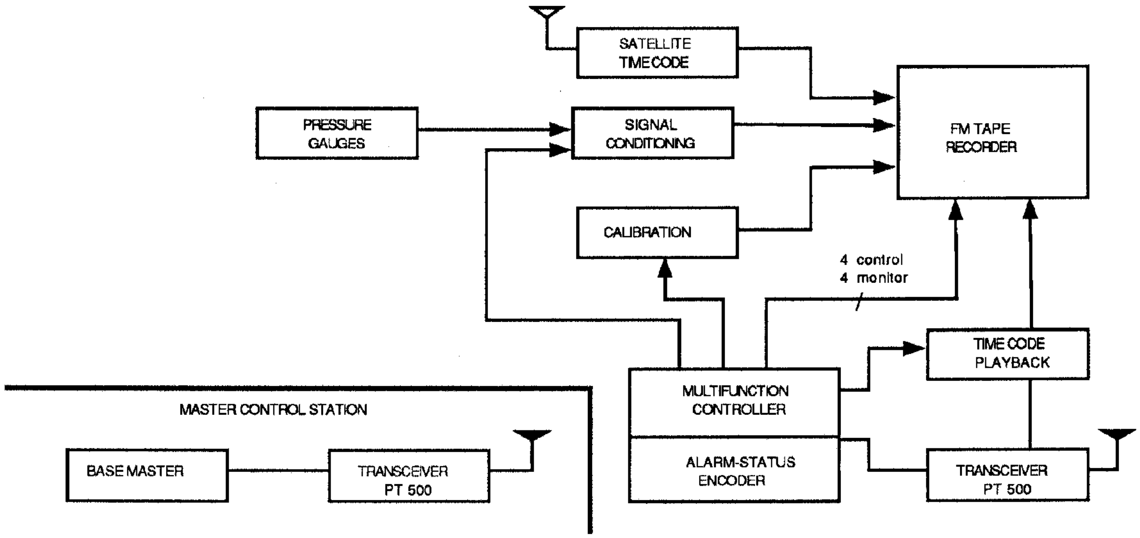


Figure 5 RIF SYSTEM BLOCK DIAGRAM

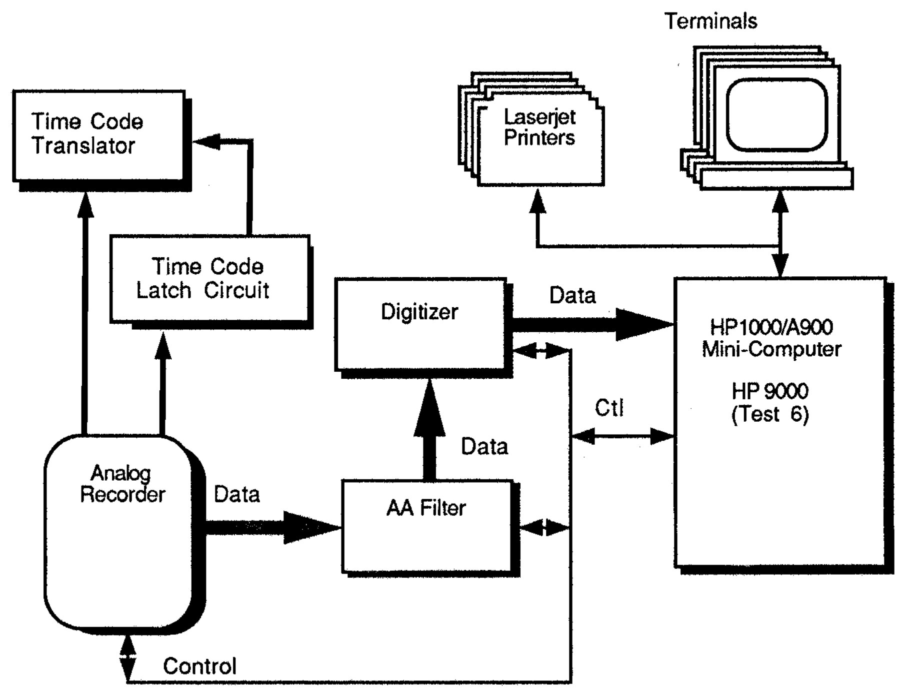


Figure 6 DATA REDUCTION COMPUTER SYSTEM

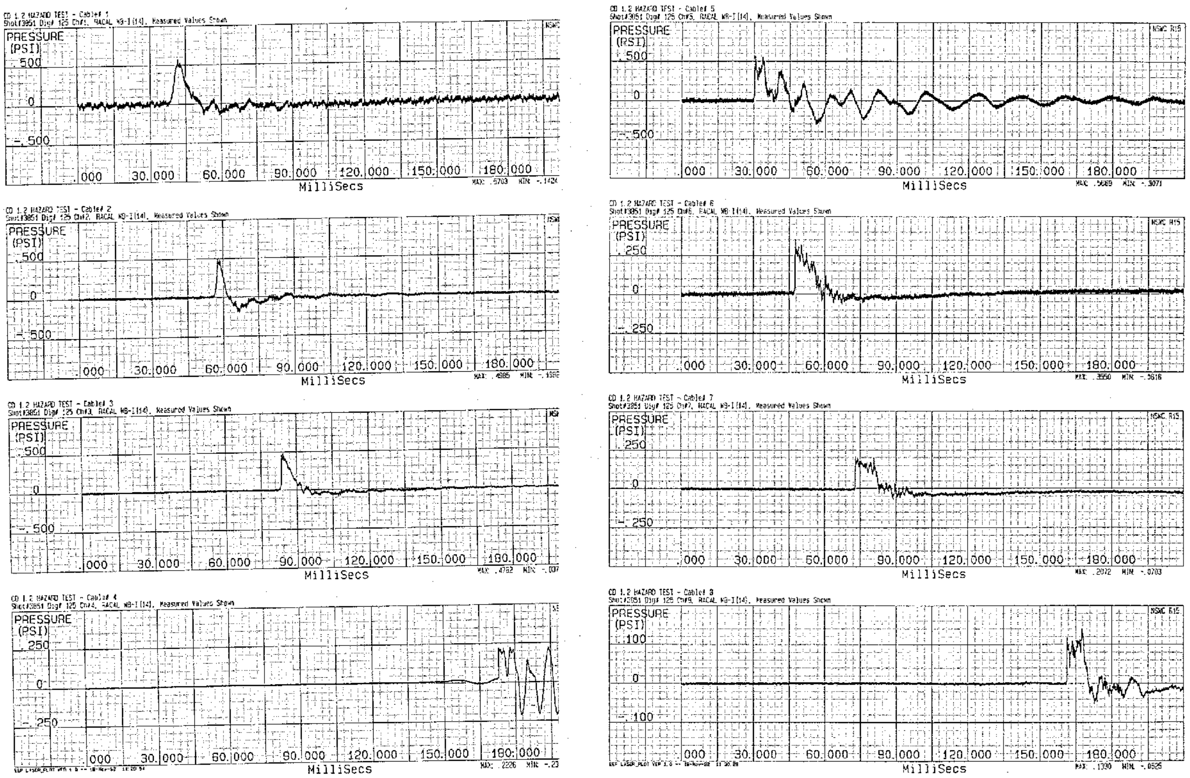


FIGURE 7a SAMPLE PRESSURE-TIME WAVEFORMS

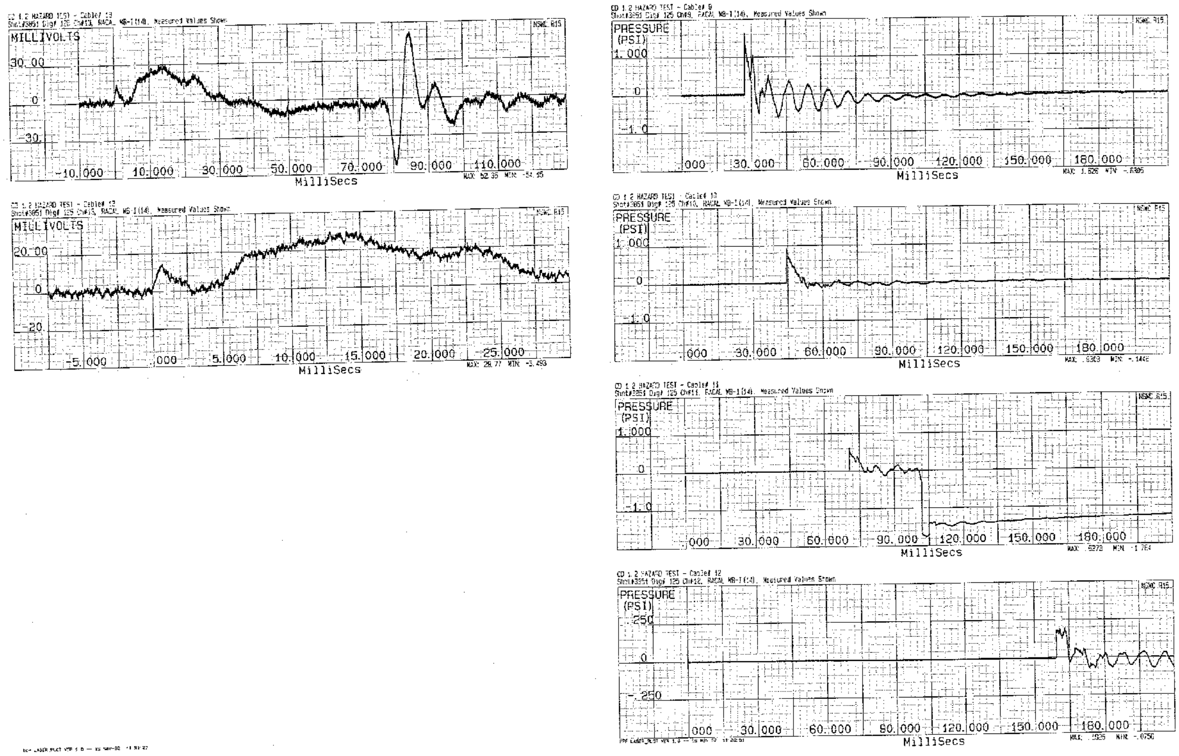


FIGURE 7b SAMPLE PRESSURE-TIME WAVEFORMS

FIGURE 8 TEST 6 CALCULATED EVENT LOCATIONS (BROAD VIEW)

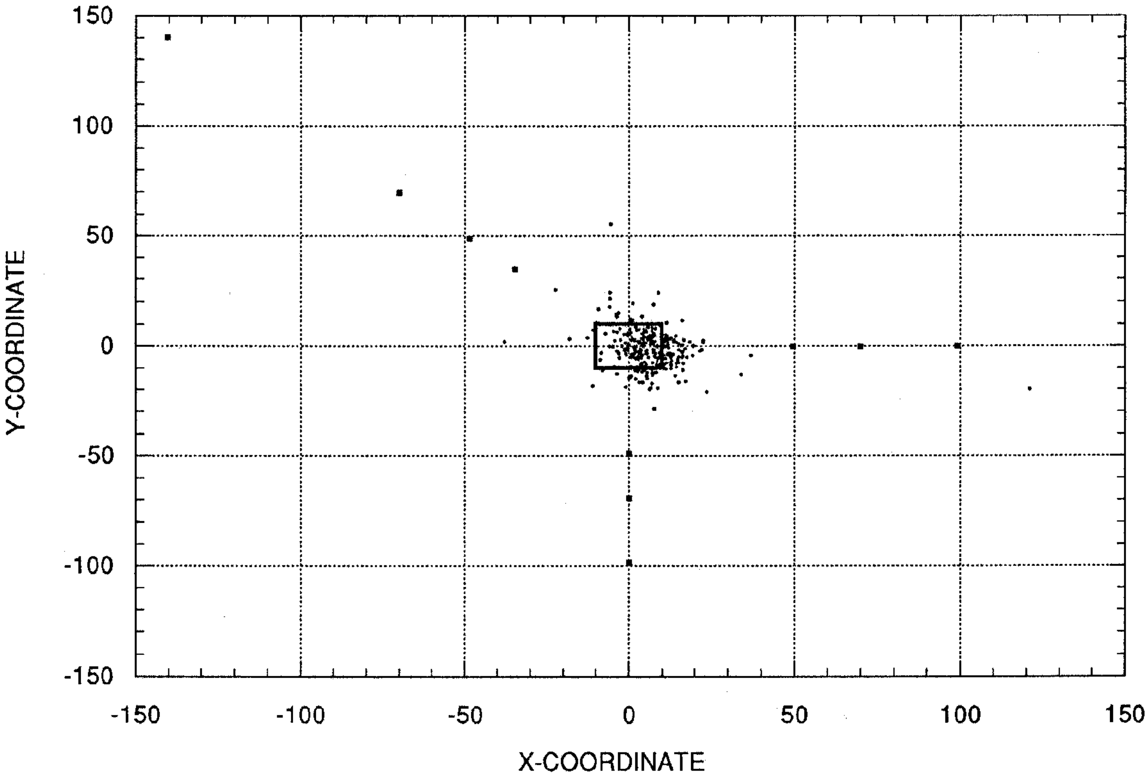


FIGURE 9 TEST 6 CALCULATED EVENT LOCATIONS (INTERMEDIATE VIEW)

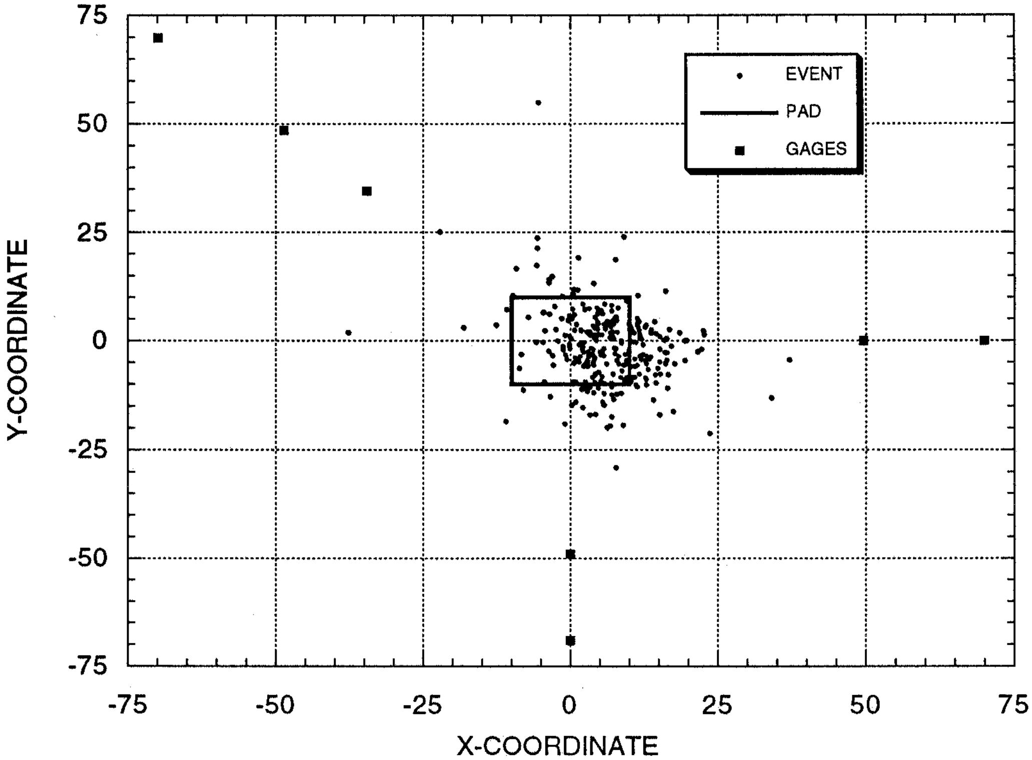


FIGURE 10 TEST 6 CALCULATED EVENT LOCATIONS (NARROW VIEW)

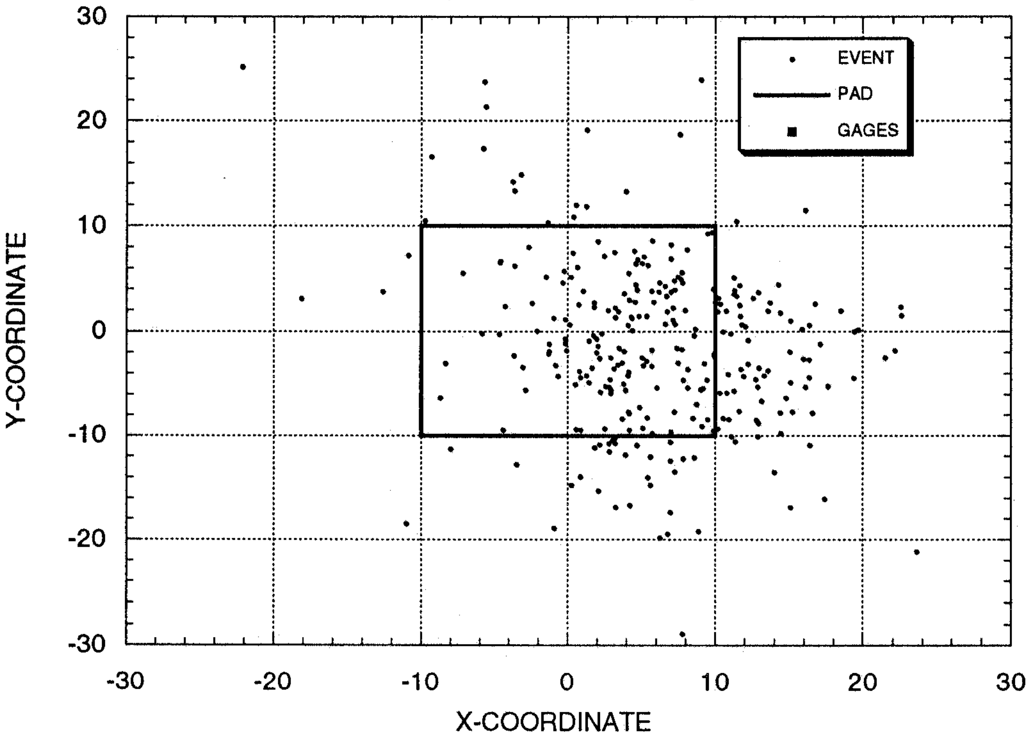


FIGURE 11 PREDICTED PRESSURE-DISTANCE CURVES

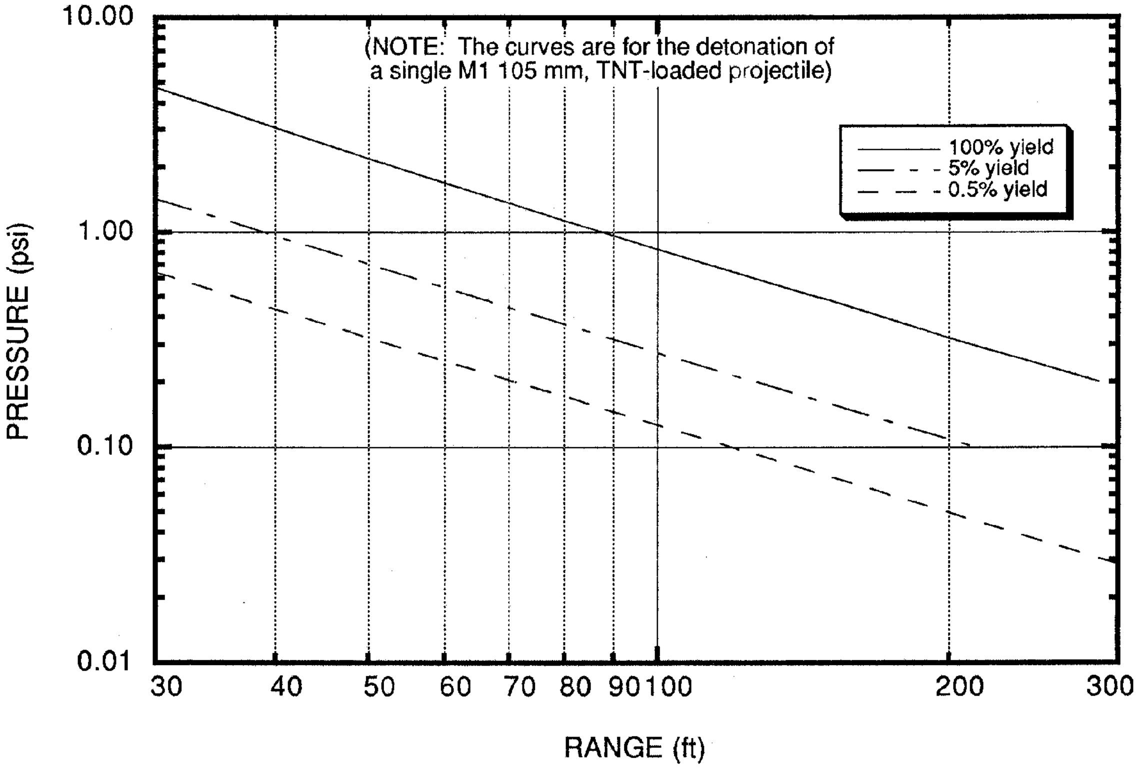


FIGURE 12 EVENT 6 YIELD ANALYSIS